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Issues with the Time of Flight System for MIPP

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1 Outstanding Issues

At the current time there are two designs for the Time of Flight system. The major difference between the two is the thickness of the scintillator in front of the aperture in the ROSY magnet. These designs will be described before proceeding onto the discussion of the two outstanding issues, i.e., what effect this extra scintillator will have on the momentum resolution and the RICH Reconstruction.

The momentum resolution will be degraded by the additional material giving rise to multiple scattering. This scattering will cause the drift chamber measurements down stream of the TOF to give less useful information. How large an effect this is on the overall momentum resolution will be studied in this document.

We also look at the production of electron-position pairs within the Scintillator material. The issue here is with those particles entering the RICH gas volume and giving extra hits which confuse the reconstruction of the Cherenkov rings. As the reconstruction code is not fully developed, we make some observations and will be as quantitative as we can.

2 The Designs

The TOF wall is located immediately before the ROSY magnet and will consist of Scintillator with R5900U phototubes. This system will measure the time of flight for the particles between the target and the scintillator to better than 200ps resolution. Using the Monte Carlo, the required size of the TOF detector was found to be 5m wide by 3m high. This completely covers the ROSY aperture and extends well beyond it.

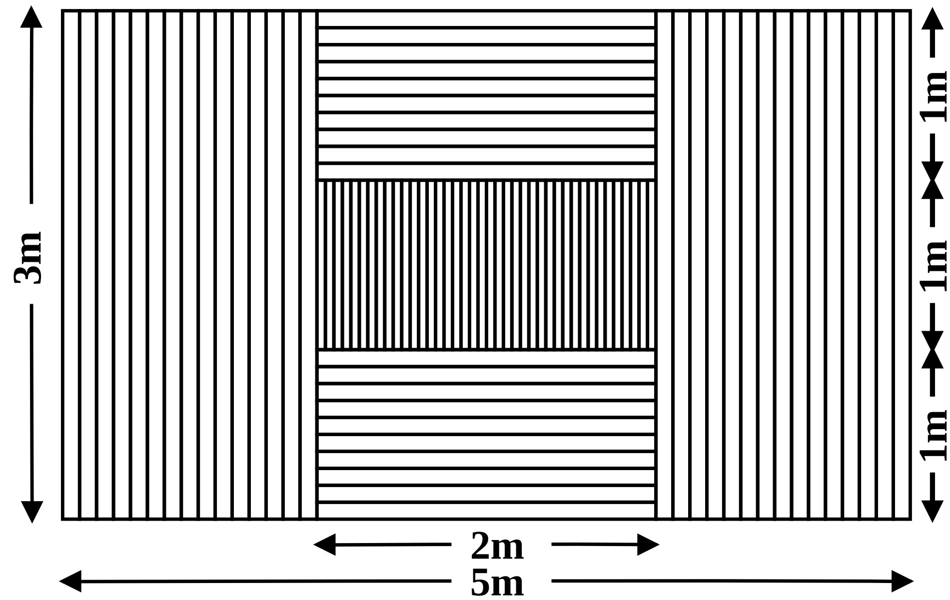

Figure 1: The Segmentation of the Time of Flight wall placed immediately before the ROSY magnet for the thin design. The center section covers the magnet aperture, and thinner scintillator is used.

A design with thin strips of scintillator is shown in Figure 1 and has 10x300 cm and 10x200cm counters around the outside of the aperture in the ROSY magnet of 10cm thickness. Covering the aperture is a section of 5x100cm by 1cm thick counters. This design is referred to as the thin design throughout this document.

The other design has the same 10x10x300cm counters on the wings in front of the ROSY Magnet, but has 5x5x300cm bars over the center of the TOF wall and in front of the aperture of the magnet. It does not have separate sections above and below the aperture with thicker scintillator. This design will be referred to as the thick design. The main advantage of this design is $40K in cost savings.

3 Momentum Resolution

One potential problem with covering the entire area with thick scintillator is that central region of the TOF wall would cover the aperture through the

ROSIE magnet. The additional material added in the flight path of those particles will degrade the momentum resolution due to multiple scattering within the TOF scintillator. The thin design was constructed to minimize this multiple scattering. Note that because of the Jolly Green Giant magnet not all of the low momentum particles pass through the aperture of the ROSY magnet.

To study the effects of multiple scattering, we use the code written by R. Raja for the "Study of Momentum Resolution and Chamber positions" . However we have had to add the effects of multiple scattering at the TOF Scintillator to get reasonable results.

The previous study used the formula

$$1/\sigma_p^2 = \sum_i (dx_i/dp)^2/\sigma_i^2$$

to get the error on the momentum resolution, σ_p, given the measurement error with chamber i is σ_i. However if we look at this formula and assume a very large multiple scattering, then (dx_i/dp) for any given chamber will be enlarged due to the multiple scattering and the corresponding momentum resolution will be small. This is contrary to our expectation. Thus we slightly change this formulation of the momentum resolution. Instead of using σ_i as the resolution of a hit at chamber i, we include the effect of the multiple scattering angle on the uncertainty of were the hit will be located on chamber i. Thus for a particle of momentum p, we calculate the multiple scattering angle as given by the PDG:

$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}[1 + 0.038\ln(x/X_0)].$$

We then use the distance between the scintillator and the chamber, L, to add an extra term in the resolution of the individual chambers set at $200\mu m$. We use 326.7cm, 417.8cm, and 1595.3cm for the distances between the TOF wall and chambers four, five, and six respectively. Thus we have the new formula as

$$1/\sigma_p^2 = \sum_i (dx_i/dp)^2/(\sigma_i^2 + \theta_0^2 L^2).$$

Using this procedure the momentum resolution was calculated for four thickness of scintillator, 1cm from the thin design and 2cm, 5cm and 10cm

Table 1: Slopes and intercepts for the momentum resolution fits for particles traveling through only 3, 5, or all 6 chambers.

Thickness of Scintillator	Three Chambers	Five Chambers	Six Chambers
	Slope ($x10^{-5}$)		
1cm	9.3 ± 0.2	5.87 ± 0.09	4.55 ± 0.06
2cm	10.1 ± 0.1	6.35 ± 0.11	5.24 ± 0.05
5cm	9.84 ± 0.06	7.39 ± 0.09	5.95 ± 0.05
10cm	9.83 ± 0.06	8.87 ± 0.14	7.00 ± 0.07
	Intercept ($x10^{-4}$)		
1cm	-0.4 ± 0.2	1.7 ± 0.2	4.3 ± 0.3
2cm	-0.9 ± 0.2	2.1 ± 0.2	3.4 ± 0.2
5cm	-0.6 ± 0.2	1.6 ± 0.2	3.4 ± 0.2
10cm	-0.5 ± 0.2	0.15 ± 0.3	2.8 ± 0.2

for the thick design. The extra two thickness are included here for completeness and sanity checks. The resulting graphs show the $\frac{\Delta p}{p}$ measurements vs. momentum assuming the particle passes through the first five chamber or all six chambers. The graphs are then fit to a line and the parameters are given on the figures. We see that the linear fit is not perfect, but it gives us a way to quantify the changes with thickness that is easy to compare. The slopes and intercepts are given in Table 1. Figure 2 shows the results with five chambers and Figure 3 shows the resolutions for all six chambers hit. We can see that increasing the thickness of the scintillator does cause the momentum resolution to get worse, but perhaps not unmanageable worse.

As a sanity check we have also included the resolution obtained in this way for particles which only hit the first three chambers. Thus these particles have stopped before hitting the TOF and should have no difference with the thickness of the scintillator. This plot is shown in Figure 4 and the values are also given in Table 1.

Carl has performed an analytical calculation that separates the contributions from the ROSY magnet and the JGG. This result is presented in another document which is forthcoming.

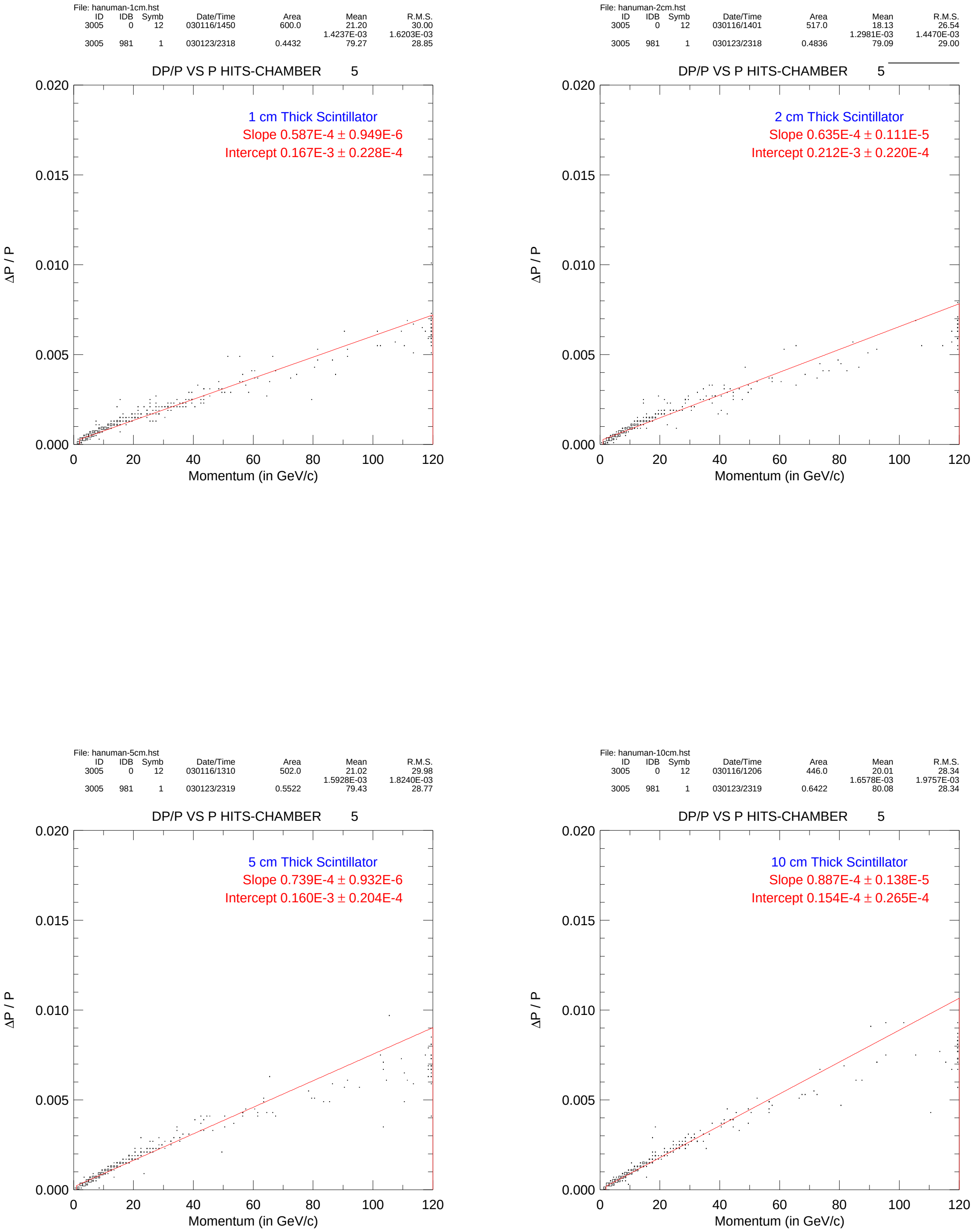

Figure 2: The momentum resolution $\frac{\Delta p}{p}$, vs the momentum for tracks going through five chambers.

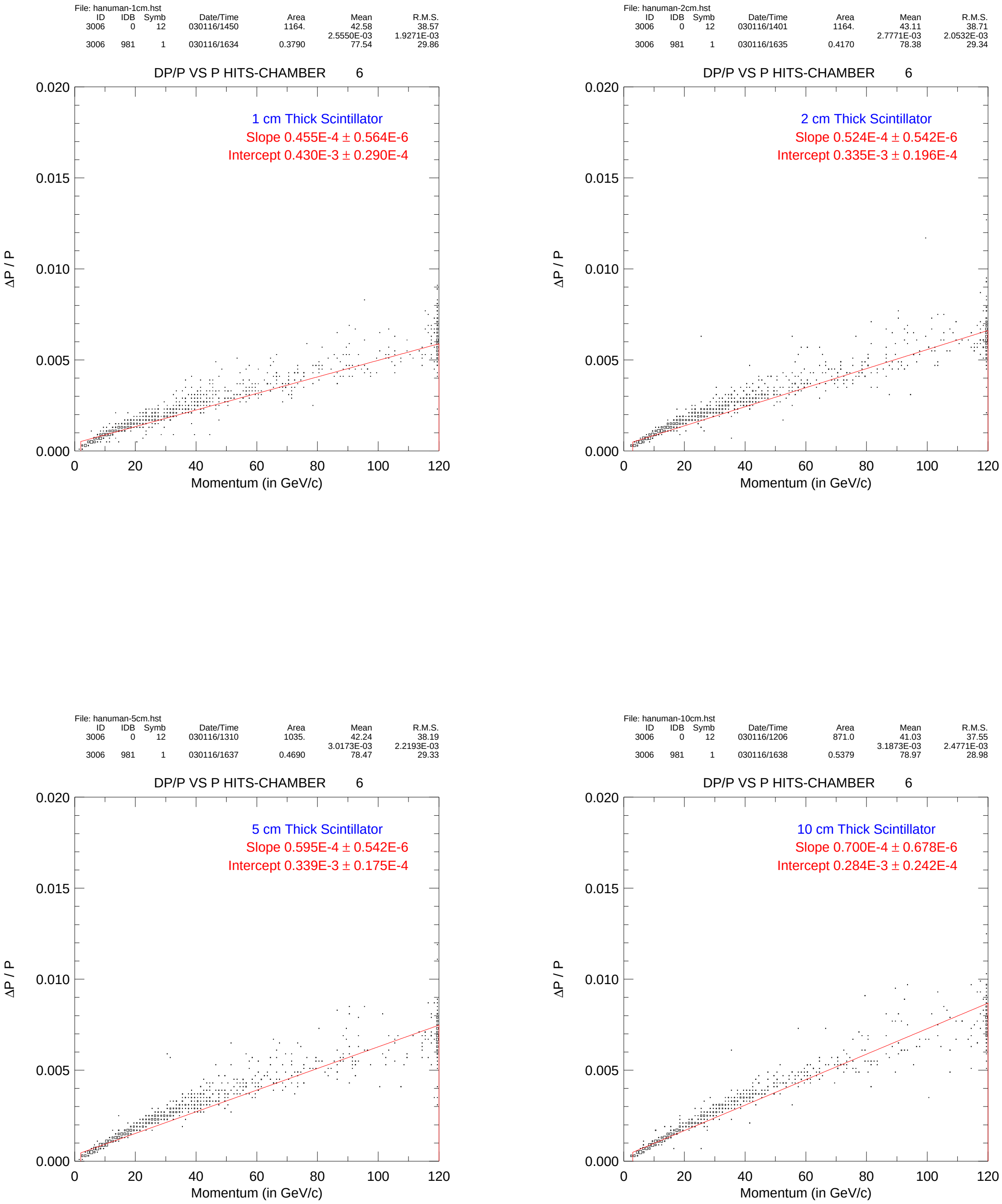

Figure 3: The momentum resolution $\frac{\Delta p}{p}$, vs the momentum for tracks going through all six chambers.

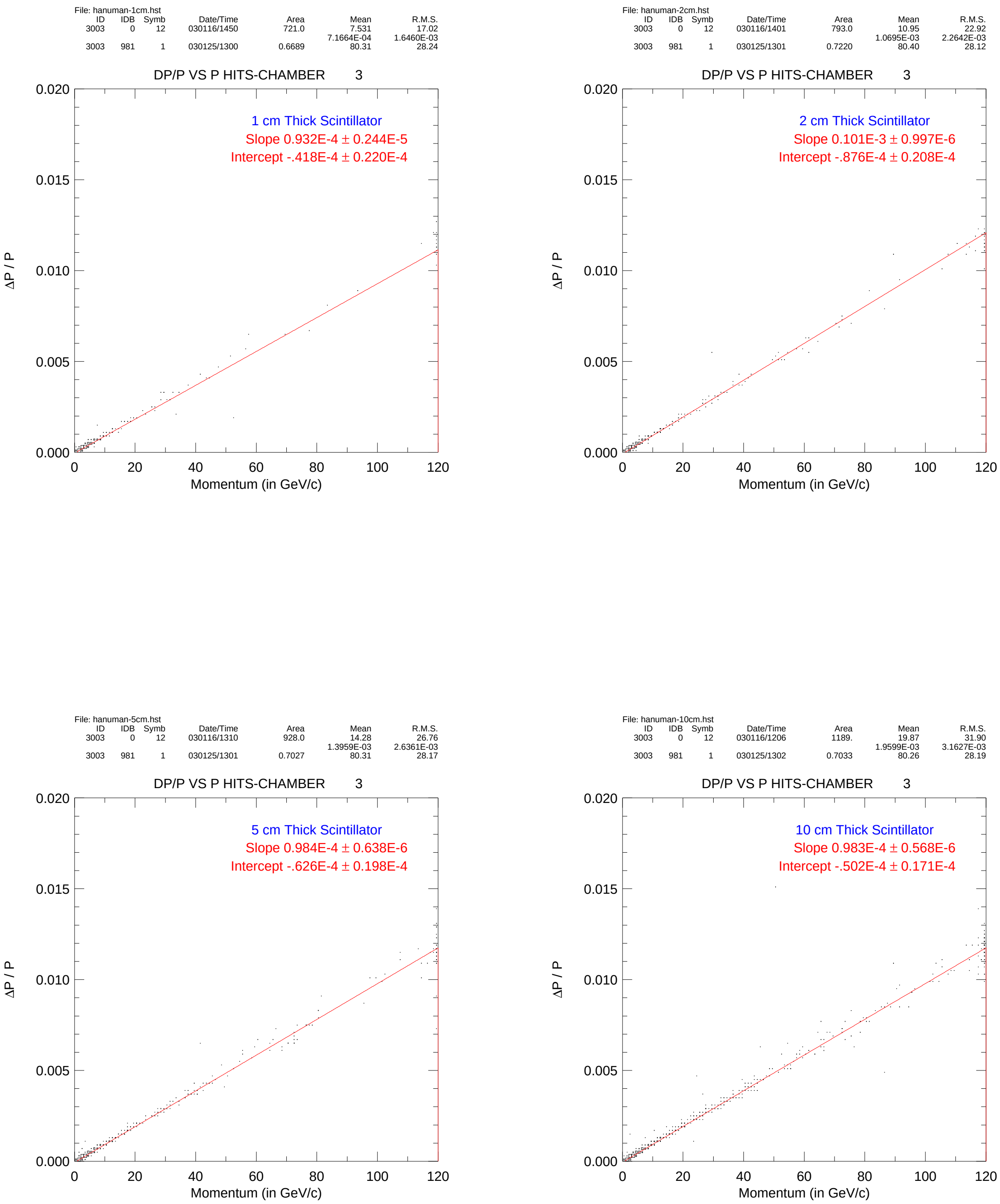

Figure 4: The momentum resolution $\frac{\Delta p}{p}$, vs the momentum for tracks going through three chambers and not the Time of Flight wall.

4 Rich Reconstruction

The other issue is with photons interacting in the material of the Time of Flight wall and producing electron-positron pairs which subsequently enter the RICH. These electron-positron pairs may become a problem for the RICH reconstruction. If these particles make it to the RICH gas volume, extra rings will occur potentially confusing the reconstruction. While a good study would be so use the reconstruction code to see how often such confusion exists, the code is not quite ready. Thus we will look at the production of electron-positron pairs and how many of them actually enter the RICH. Additionally 50 events for each of the two detector designs were generated and were looked at with the detector display to visually see the effects of the extra material.

Sharon Seun has generated displays of 50 events passing through the detector. The detector displays are located at http://huhepl.harvard.edu/ seun in the folders tof and tof-thin for the thick and thin designs. Looking at these plots it was concluded that there was not much difference between the two designs as far as the RICH hits, in cyan, were concerned. If we were to classify the events as perfectly clean, clean, somewhat dirty and dirty we get the results shown in Table 2, where some of the events were double classified when there was a doubt. These values are subjective but seem to indicate that there should be no problem with either thickness of scintillator. For the record the somewhat dirty events were: 11,20,25 and 33 for the 1cm thick and 9, 20 and 25 for the 5cm thick. The dirty events were: 8 and 11 for the 1cm thick and 20 and 25 for the 5cm events. The clean events were 16 in the 1cm thick, and 3 and 11 for the 5cm thick. A clean event from each of the two designs is shown in Figure 5. We show a sample of the thin design in Figure 6 and the thick design in Figure 7.

The next thing that was studied is the production of electron-positron pairs in the TOF wall for various thicknesses. We use the Monte Carlo and look at the number of positrons which are created in that volume. We can then record how many of these positrons actually enter the RICH gas volume. For the 1000 Pythia events generated we note that that there were 4250 photons generated at the primary vertex and about 3800 photons actually hitting the TOF wall.

We then look at the particles which hit the Time of Flight counters. The number of positrons which are created in the counters are counted. We have

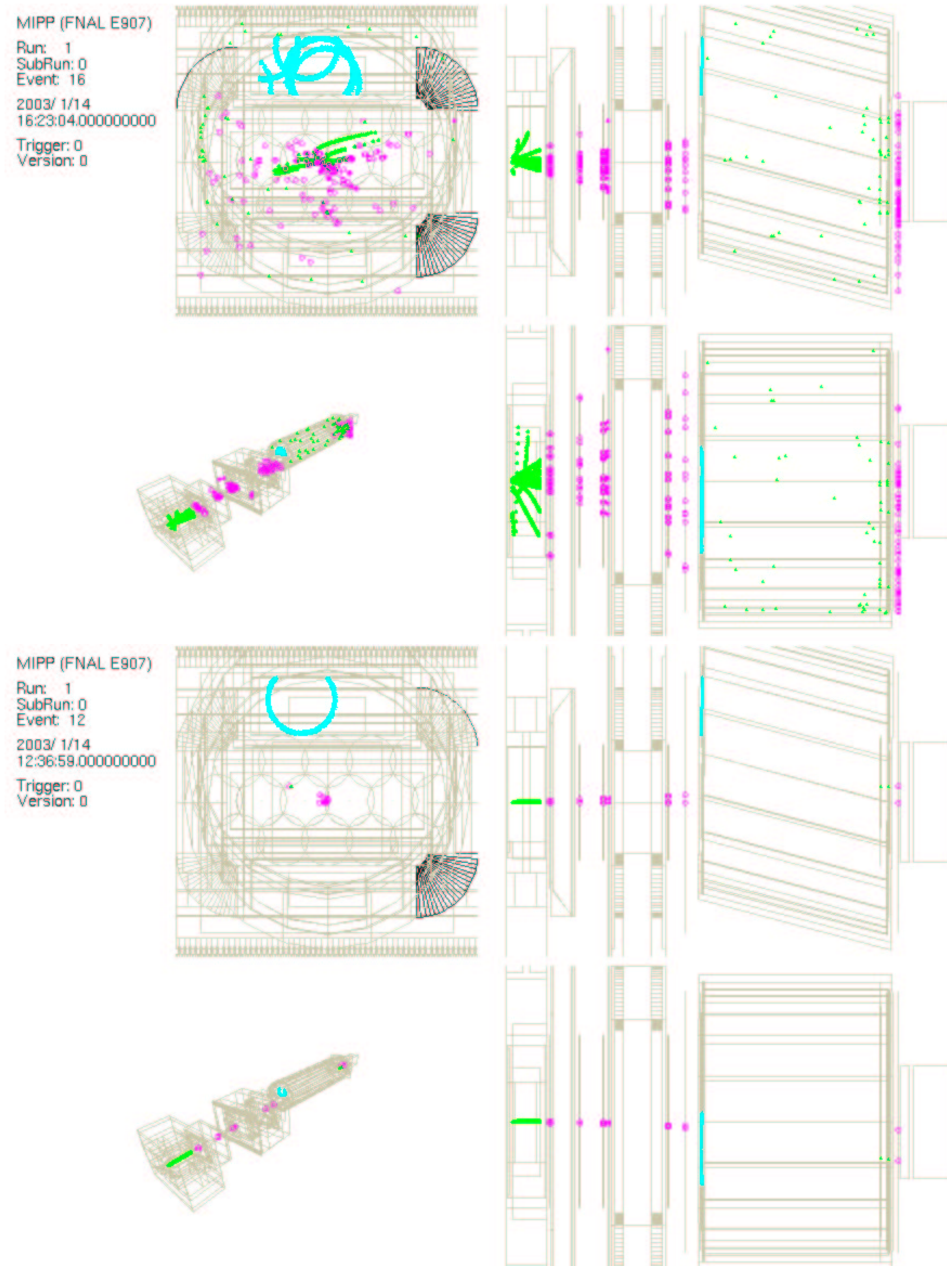

Figure 5: Examples of clean events from the Monte Carlo with the thin(top) and thick(bottom) design. The cyan points are the hits in the RICH phototubes.

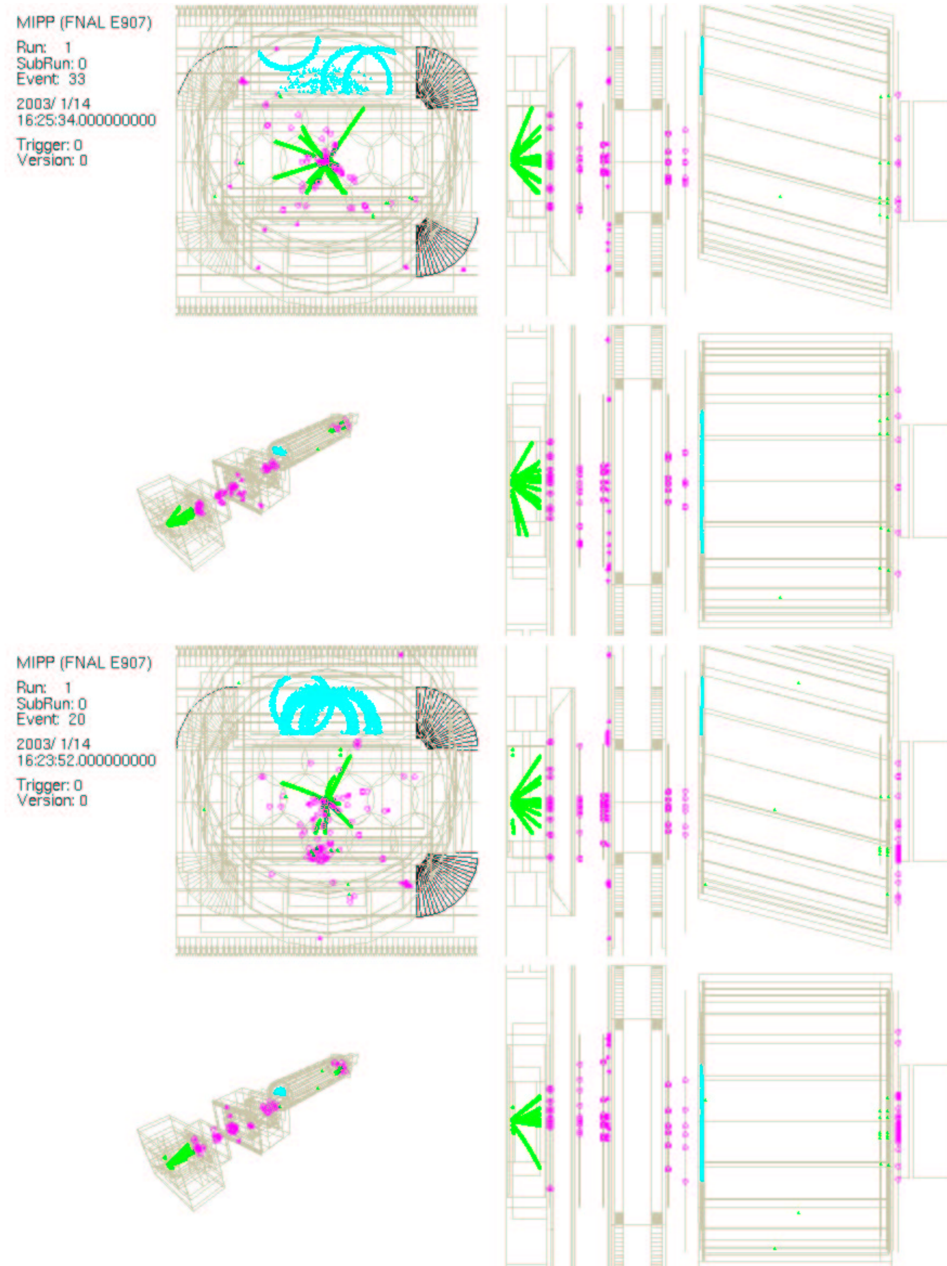

Figure 6: Examples of dirty events from the Monte Carlo with the thin design. The cyan points are the hits in the RICH phototubes.

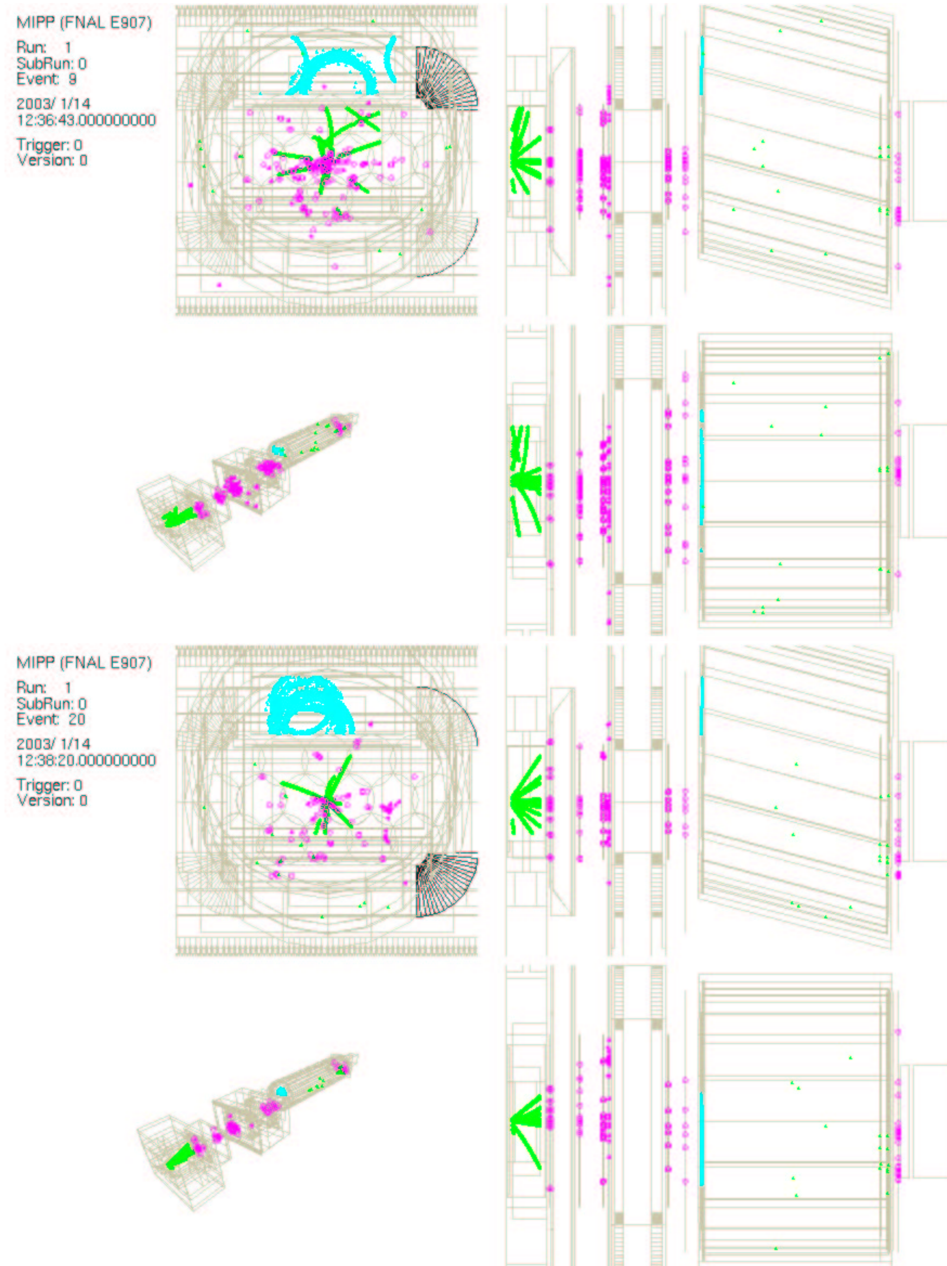

Figure 7: Examples of clean events from the Monte Carlo with the thick design. The cyan points are the hits in the RICH phototubes.

Table 2: Classification of event displays with 1cm and 5cm thick scintillator in front of the ROSY magnet.

	Perfectly-Clean	Clean	Somewhat-Dirty	Dirty
1cm	46	1	3–4	1–2
5cm	45	2	2–3	1–2

Table 3: Number of positrons produced in the experiment and entering the RICH gas volume. We also give the number which have both properties of created in the TOF and entering the RICH.

Thickness	e^+ created in TOF	Entering RICH	Both
1 cm	68	278	27
2 cm	98	275	51
5 cm	359	302	83
10 cm	992	414	189

also looked at the number of positrons entering the RICH gas volume, as well as the number of those which were generated in the Time of Flight scintillator. In this way, we can quantitatively look at the electron positron pair production and its impact on the RICH. These values are summarized in Table 3.

5 Conclusions

The general conclusion is that going from 1cm to 5cm thick, does neither have a big effect either on the momentum resolution nor on RICH reconstruction. There is an effect on momentum resolution but is not enough to cause great concern. Similarly, the extra electron-positron pairs generated in the thicker scintillator, while they do make it to the RICH, do not seem to significantly cause a confusion in the ring patterns as shown in the event pictures.

While we see no gain using the thinner scintillator the draw backs are the special "box" design and the additional cost of $40k. The 5cm thick option, is simpler and cheaper. Thus, we are proposing to go with the 5cm design.